Furrow erosion and sediment losses on irrigated cropland

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ABSTRACT: Sediment losses from furrow erosion on irrigated cropland ranged from 0.5 to 141 metric tons per hectare (0.2 to 63.0 tons/acre) on 49 Idaho fields during one irrigation season. Field slope varied from 1.0 to 5.0 percent and furrow stream size from 11.3 to 49.9 liters per minute (3.0 to 13.2 gal/min). Erosion increased sharply on row-cropped fields when slopes exceeded 1.0 percent. Furrow erosion can be reduced by: (a) reducing furrow stream size when water reaches the furrow ends, (b) avoiding irrigation of row crops on slopes that are too steep, (c) keeping the tailwater ditch shallow and the water in it moving slowly, (d) installing tailwater control systems, and (e) alternate-furrow irrigation. Sediment losses from irrigated lands can also be reduced markedly by planting vegetative filter strips and using sediment retention basins. Total phosphorus losses were reduced in proportion to the reduction in sediment losses.

As long ago as 1946, excessive erosion on irrigated lands threatened the permanence of agriculture in arid regions of the United States (6). Farmers reported serious damage when attempting to irrigate steep slopes unless the furrow stream size was small (4). They recognized that little erosion occurred on relatively flat land, even with large furrow streams.

Today, 34 years later, some farmers still irrigate on steep slopes with relatively large furrow streams. Despite advances in erosion control technology and improvements in equipment, serious erosion problems on furrow-irrigated land continue.

The question in the 1940s and now remains: What rate of erosion will occur with various stream sizes on various slopes?

Literature review

Six factors influence the amount of erosion on furrow-irrigated land: field slope, furrow stream size, soil type, crop, field length, and duration of irrigation.

Mech (7) reported soil losses of 50.9 metric tons per hectare (22.6 t/a) on a 7 percent slope during a 24-hour irrigation of corn on Sagemoor fine sandy loam. On relative flat fields with short runs, 30 centimeters (12 in) of surface soil were sometimes lost after about 10 years of cultivation. In a Utah study (6), furrows near the head ditches eroded between 2.5 and 10 centimeters (1-4 in) in one season. Sediment filled the lower ends of the furrows.

The stream size required to irrigate a field depends upon furrow length, soil type, and crop condition. Irrigation water must reach the end of the furrow to maintain infiltration for the entire furrow length to provide the water required by a crop, but runoff at the furrow end is wasteful. Surface runoff usually is considered to be 10 to 30 percent of the applied water (3). This runoff carries sediment and plant nutrients from the fields and encourages silting and drainage problems. Normally, irrigation begins with a large stream size to get the water to the end of the furrow. The flow should then be reduced, but this is not common practice. An irrigator's experience should be a reliable guide to the proper stream size.

More erosion usually occurs on a long field than a short one because a larger stream size is required to get water to the end of the furrow. The larger stream erodes more near the head of the furrow, but some sediment may be deposited within the furrow and therefore not leave the field. Short fields require more labor to irrigate, and additional cross-ditches interfere with cultivation, tillage, seeding, and harvesting operations.

Silt loam soils are very erosive, particularly after tillage. Even small furrow streams erode such soils on sloping land. Generally, erosion is less on soils containing greater amounts of crop residue, but too much residue can clog furrows, causing streams to cross over to other furrows.

Soils supporting solid-stand crops, such as alfalfa and established grains and grasses, erode very little. A common practice for controlling erosion on steep slopes has been to establish solid plant cover.

More water and labor efficiency is gained by irrigating deep-rooted crops longer and less often, using small furrow streams to avoid excessive runoff. Care must be exercised to avoid irrigating too long, thereby preventing excessive deep percolation losses (3). Each irrigation adds to a field's soil and nutrient losses.

Alternate furrow irrigation can also reduce erosion by reducing the area of soil-to-water contact. Sometimes the furrow that was not irrigated the first time is irrigated the second time, but often the same furrows are irrigated the entire season.

Our report demonstrates the effects of furrow slope and stream size on sediment and phosphorus losses from fields supporting different crops, including sugarbeets, beans, alfalfa, peas, corn, and cereal grain, grown on erosive soil during one irrigation season.

Study methods

We studied 49 fields, all on Portneuf silt loam (Durixerollic Calciorthid), during the 1978 and 1979 irrigation seasons in southern Idaho. Twenty-three cooperating farmers operated 46 fields. One field was on the University of Idaho Research and Extension Center farm near Kimberly, and two fields were on the Snake River Conservation Research Center farm, also near Kimberly. Data are reported from 33 fields: 1 alfalfa, 4 corn, 5 cereal grain, 14 dry bean, 5 sugarbeet, and 4 dry pea fields. We excluded data from the other fields because the information was nearly the same as for the fields reported.

We collected water samples for sediment and chemical analysis during as many irrigations as possible on each field. Usually we collected the first sample when the water reached the ends of the furrows and took three or four additional samples during each irrigation. We measured furrow inflows and outflows each time samples were collected, and recorded the duration of each irrigation. Samples included 2 liters (1.9 quarts) collected at the head ditches supplying water to the fields and at the ends of selected sampling furrows. Two additional, 200-milliliter (7-fl oz) samples were taken at the same location and time for chemical analysis.

All samples were taken to the laboratory the day they were collected. Sediment samples were filtered and the residue dried and weighed. Water-soluble and total phosphorus were determined on the 200 milliliter samples (2).

Using these data, we calculated the sediment and phosphorus losses in excess of inflows for each irrigation. Values were computed for each time segment of each irrigation by using average values for two successive times and calculating quantities for a given time period between the two samplings. We added quantities for each time period to give total sediment and phosphorus losses for each irrigation. The sum of the totals for each irrigation gave us seasonal quantities. For those irrigations

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not sampled, we used average values for irrigations just before and after.

Our streamflow measurements on water entering and leaving the furrow were made with small trapezoidal, 60-degree flumes. Sediment samples were collected at the furrow ends with a pipe welded to a triangular piece of sheet metal. This sampling device, when inserted into the furrow, diverted the stream into the pipe. Samples were then collected at the end of the pipe.

We measured the slope and furrow lengths on all fields.

Results and discussion

Slope on the 49 fields varied from 1 percent to 5 percent. Erosion and sediment loss were more severe on fields with slopes exceeding 1 percent, especially fields in row crops—corn, dry beans, and sugarbeets (Table 1). The relationship between slope and sediment loss also held with cereal grain, but sediment loss was only about one-tenth that for row crops. No sediment loss was measured from alfalfa fields. In fact, alfalfa removed sediment from the irrigation water.

Sediment losses were highest from sugarbeet fields because more irrigations were applied to this long-season row crop than to other row crops. One sugarbeet field with a 4 percent slope lost 141 metric tons of sediment per hectare (63 t/a) in one season. This is equivalent to a depth of 8 to 9 millimeters (.3-.4 in) of soil over the entire field. A farm will not remain productive for many years at this rate of soil loss.

Total phosphorus losses tended to relate to sediment losses, but there were exceptions. Significant quantities of total phosphorus were lost from several fields. This is of concern because phosphorus is a nonrenewable resource.

Soluble phosphorus losses varied widely but generally were less than 10 percent of the total phosphorus loss. Sugarbeet field number four was an exception; there, soluble phosphorus was nearly 30 percent of total phosphorus.

In only 4 of the 49 fields did less than 30 percent of the water applied become surface runoff. Surface runoff accounted for 50 percent or more of the water applied on 13 fields. These results indicate that furrow streams were considerably larger than needed. Our observations also indicated that few farmers reduced furrow stream inflow after setting the water at the beginning of the irrigation. This practice conserves labor, but increases erosion. Furrow streams can be reduced manually or by using automatic cutback systems (5).

Furrow erosion varied considerably during the irrigation season (Table 2). Generally, irrigations early in the season caused more erosion and sediment loss than later irrigations, when cultivations had ended, plant leaves and stems were in the furrows, and root systems were extensive. Corn field number two was an exception, but the later irrigation was with a furrow stream more than twice the size used in the early irrigation (Table 2). These results stress the importance of proper irrigation management early in the season to control erosion and sediment loss.

We did not measure sediment deposition

Table 1. Field characteristics, furrow flow, and sediment and phosphorus losses during the 1978 irrigation season*.

Crop	Slope (%)	Furrow Length (ft)	Furrow Length (m)	Furrow Inflow (gpm)	Furrow Inflow (l/min)	End Furrow Outflow (gpm)	End Furrow Outflow (l/min)	Run-off (%)	Sediment Loss (t/a)	Sediment Loss (mt/ha)	Ortho Phosphate Loss (lb/a)	Ortho Phosphate Loss (kg/ha)	Total Phosphate Loss (lb/a)	Total Phosphate Loss (kg/ha)
Corn														
1	2.5	636	194	6.3	24.0	2.7	10.2	43	16.5	37.0	0.59	0.66	28.6	32.1
2	2.5	697	212	7.0	26.4	3.5	13.2	50	16.5	37.0	0.45	0.50	18.4	20.6
3	1.0	1,026	313	13.2	49.9	6.2	23.5	47	2.4	5.4	0.47	0.52	6.0	6.7
4	1.0	856	261	10.5	39.7	4.2	15.9	40	0.35	0.78	—	—	—	—
Cereal grain														
1	5.0	721	220	5.3	20.1	1.6	6.0	30	1.6	3.6	0.06	0.07	4.4	4.9
2	3.0	721	220	4.3	16.3	0.9	3.4	21	2.0	4.5	0.	0.	5.1	5.7
3	1.5	789	240	5.3	20.1	3.3	12.5	62	1.0	2.2	0.28	0.31	24.7	27.7
4	1.0	498	152	8.7	32.9	5.0	18.9	67	0.20	0.45	0.22	0.25	2.6	2.9
5	1.0	433	132	4.7	17.8	2.9	11.0	62	0.20	0.45	0.03	0.03	0.2	0.3
Beans														
1	3.0	704	285	3.88	14.2	2.14	8.1	57	25.4	56.9	0.34	0.38	36.8	41.3
2	3.0	751	229	4.6	17.4	2.3	8.7	50	13.6	30.4	0.03	0.03	1.2	1.3
3	2.0	647	197	4.4	16.6	2.6	9.8	59	13.9	31.1	0.09	0.10	7.2	8.1
4	1.5	570	174	3.0	11.3	1.3	4.9	43	2.4	5.4	0.02	0.02	15.3	17.2
5	1.5	591	180	3.7	13.6	1.9	6.8	50	4.8	10.7	1.5	1.7	16.5	18.6
6	1.5	977	298	4.7	17.7	1.7	6.3	36	3.0	6.7	0.15	0.17	14.0	15.7
7	1.5	518	158	5.6	21.2	2.6	9.8	46	13.2	29.6	0.10	0.11	1.2	1.3
8	1.5	609	186	5.4	20.4	2.0	7.6	37	10.4	23.3	0.61	0.68	20.2	22.6
9	1.0	925	282	6.5	24.6	2.3	8.7	35	1.9	4.3	0.07	0.08	4.6	5.2
10	1.0	669	204	6.2	23.5	3.1	11.7	50	4.8	10.8	0.03	0.03	0.3	—
11	1.0	870	266	5.9	22.3	2.4	9.1	41	3.5	7.8	0.06	0.07	4.0	4.5
12	1.0	759	231	7.4	28.0	2.5	9.5	34	1.4	3.1	0.10	0.11	4.9	5.5
13	1.0	871	265	7.7	29.1	1.6	6.0	21	1.1	2.5	0.19	0.21	1.9	2.1
14	1.0	469	143	4.0	15.1	1.7	6.4	42	1.1	2.5	0.04	0.04	0.6	0.7
Sugarbeets														
1	4.0	704	214	4.7	17.8	2.5	9.5	53	63.0	141.0	1.0	1.12	116.5	130.6
2	2.0	557	170	5.6	21.2	3.5	13.2	62	11.5	25.8	0.32	0.36	9.5	10.6
3	1.0	713	217	4.8	18.2	2.7	10.2	56	12.0	26.9	0.30	0.34	25.5	28.6
4	1.0	403	123	3.7	14.0	2.3	8.7	62	5.3	11.9	2.1	2.35	7.1	7.9
5	1.0	792	241	4.4	16.6	2.1	7.9	48	2.2	4.9	0.32	0.36	3.3	3.7
Peas														
1	1.5	632	193	5.9	22.3	2.3	8.7	39	5.3	11.9	0.1	0.11	—	—
2	1.0	631	192	7.3	27.6	3.2	12.1	44	0.7	1.6	0.08	0.09	1.0	1.11
3	1.0	459	140	5.5	20.8	2.4	9.1	44	1.9	4.2	0.03	0.03	3.1	3.5
4	1.0	629	192	8.3	31.4	2.5	9.5	30	0.36	0.80	0.03	0.03	0.22	0.25
Alfalfa														
1	1.0	506	154	7.8		2.9		37	0.	0.	0.9	1.0	1.0	1.1

*Data are averages of all samples for streamflow and accumulated totals for sediment and phosphorus losses for each field in the 1978 or 1979 irrigation season.

within furrows, only the net sediment loss from irrigated fields. Work is underway at the Snake River Conservation Research Center to evaluate sediment deposition within furrows, however.

Control of erosion and sediment loss

In addition to controlling furrow stream size by cutback methods and by avoiding row-crop irrigation on steeper slopes, there are other practices to reduce erosion and sediment losses on furrow-irrigated farms. These same practices will reduce phosphorus losses as well.

A common practice on furrow-irrigated land is to keep the tailwater ditch 15 centimeters (6 in) or more deeper than the ends of the furrows and the slope steep enough so that tailwater flows rapidly from the field (*1*). This practice causes erosion. As the furrow stream drops into the furrow, the energy of the falling water erodes soil into the tailwater ditch. A small waterfall develops; and as the lip of the fall erodes away, the waterfall moves up the furrow (Figure 1). Another small waterfall develops and follows the first, and so on. Irrigation furrows often erode 5 to 20 meters (16-65 ft) from the lower ends (Figure 2).

This erosion does not appear severe, but it continues with each irrigation and each year until the shape of the lower end of the field becomes convex, with increasing slope into the tailwater ditch. Then, even small furrow streams cause erosion because the added slope boosts the soil-eroding energy of the flowing water.

This problem can be avoided by keeping the tailwater ditch shallow and the water in it moving slow enough so the sediment settles out. The Snake River Conservation Research Center is evaluating a new management practice that uses a buried pipe drain system and small sediment basins.

Another means of reducing erosion and sediment losses from fields is to plant and maintain a vegetative filter strip along the lower end of the field (Figure 3). Runoff water from the furrows passes through the vegetation filter, which reduces flow and filters sediment. Vegetative filters can be grasses, cereal grains, alfalfa, or any dense-stand crop. Ideally, farm production and erosion control can be meshed if the cover crop is grown elsewhere on the farm. Production area is not lost when, for example, a double-seeded cereal grain crop is used and harvested when grain fields elsewhere on the farm are harvested (Figure 4) or a strip of alfalfa is left when alfalfa fields are plowed in the normal rotation. This alfalfa filter strip can remain until the field is seeded again to alfalfa or another dense-stand crop.

Table 2. Differences in furrow sediment losses between early and late irrigations.

Crop	Date of Irrigation	Furrow Inflow (gpm)	Furrow Inflow (l/min)	End Furrow Outflow (gpm)	End Furrow Outflow (l/min)	Runoff (%)	Sediment Loss (lb/a)	Sediment Loss (kg/ha)
Corn								
1	7/20	4.9	18.5	2.0	7.6	41	5,754	6,450
1	8/30	6.9	26.1	3.2	12.1	46	4,527	5,075
Corn								
2	7/21	4.0	15.1	1.4	5.3	35	1,534	1,720
2	8/30	8.4	31.8	4.9	18.5	58	1,536	1,722
Cereal grain								
1	6/23	5.2	19.7	3.6	13.6	69	74	83
1	8/14	5.5	20.8	3.3	12.5	60	0.29	0.32
Cereal grain								
2	6/27	5.1	19.3	3.0	11.3	58	3,962	4,441
2	7/7	5.6	21.2	3.6	13.6	64	18	20
Beans								
8	6/30	8.2	31.0	2.3	8.7	28	515	577
8	7/31	7.7	29.1	1.1	4.2	14	125	140
Beans								
10	5/22	7.0	26.5	3.5	13.2	50	743	833
10	8/16	8.4	31.8	2.8	10.6	33	206	231
Beans								
11	5/26	10.1	38.2	4.4	16.6	43	1,077	1,207
11	8/2	5.4	20.4	1.7	6.4	31	0	0
Sugarbeets								
1	6/13	5.5	20.8	2.5	9.5	46	20,449	22,923
1	8/9	4.0	15.1	1.5	5.7	38	2,958	3,316
Sugarbeets								
2	7/5	4.2	15.9	2.6	9.8	62	3,626	4,065
2	8/21	4.5	17.0	2.6	9.8	58	252	282
Sugarbeets								
3	6/16	4.1	15.5	2.0	7.6	49	4,329	4,853
3	8/11	6.1	23.1	3.7	14.0	61	508	569
Peas								
1	6/1	8.2	31.0	2.7	10.2	33	198	222
1	6/21	8.7	32.9	1.5	5.7	17	40	45
Peas								
2	6/5	6.2	23.5	4.3	16.3	69	4,350	4,876
2	6/19	5.8	21.9	2.4	9.1	41	2,344	2,628
Peas								
3	6/12	4.1	15.5	2.6	9.8	63	3,475	3,895
3	6/28	7.6	28.8	2.1	7.9	27	740	829

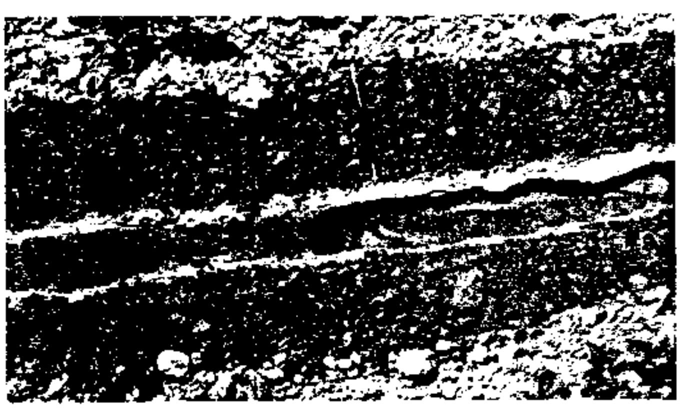

Figure 1. Waterfalls appear where the furrow stream drops into the deeper tailwater ditch. As the soil erodes, these waterfalls move upstream along the furrow.

Figure 2. A series of small waterfalls move upstream along each furrow, subtly eroding away the lower end of the field.

Figure 3. This orchard grass strip effectively filters eroded soil at the lower end of a potato field.

Figure 4. A strip of spring wheat filters eroded soil at the lower end of this sugarbeet field. Wheat is harvested with other wheat on the farm so production area is not lost.

Figure 5. This sediment basin was constructed on a farm drain.

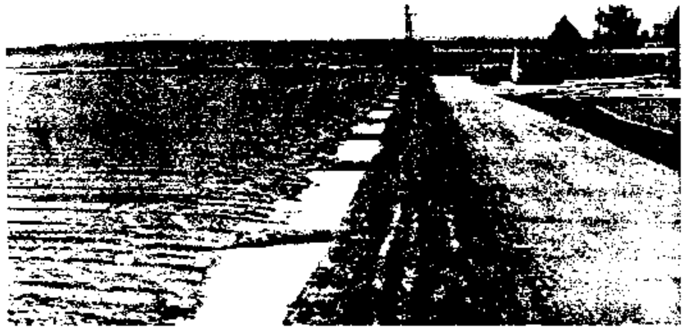

Figure 6. Minibasins at the lower end of this bean field outlet into a buried drain runoff control system being evaluated at the Snake River Conservation Research Center. Minibasins can outlet into a tailwater ditch. Sediment retained at the lower end of the field corrects the convex shape resulting from years of erosion.

Vegetative filters must be managed properly. Furrows should be pulled into the vegetative filter so that sediment does not settle at the upper edge of the filter strip and block water from entering. Occasionally removing sediment from the filter strip may be necessary to avoid excessive buildup in elevation.

Sediment retention basins or sediment ponds are also useful in controlling sediment loss from farms. Sediment basins can be constructed along main irrigation-tract drains on single-farm drains (Figure 5), on field drains, or along the ends of fields with inflow from only a few furrows. The latter are usually called minibasins (Figure 6). Sediment removal efficiency ranges from 65 to 95 percent, depending upon the size and shape of the basin and the sediment load and flow-through time. Flow-through time is the time required for water entering the basin to reach the outlet and leave the basin. Results are best if flow-through time is 2 hours or longer. One simple sediment basin collected 2,390 metric tons (2,633 t) of sediment from a 117 hectare (289 a) tract in two seasons (*8*).

Sediment collected in retention basins is a valuable resource. The material can be used to cover rocky areas or fill in low areas, to combine fields into better operating units, and for landscaping. Site selection is very important to keep costs of removing sediment from the basins and transporting it to an area of use as low as possible. Where possible, basins should be located where the sediment can be farmed in place after it is collected. Often, low areas along drainage streams can be filled with sediment by constructing a check on the drain. After the low area is filled, water can be diverted through a channel or pipe, allowing the sediment to become part of an adjacent field.

Other practices can be used to reduce erosion in irrigation furrows. One is to shorten run length by using a multiset system of gated pipe that can be removed before the field is cultivated. Buried pipe can also be used so that farm equipment can cross without damaging it.

Another practice is to irrigate every other furrow, which reduces the area of soil-to-water contact. Lateral water movement must be sufficient to meet crop needs, however. In some cases, alternate furrows are used when water intake is high. Later in the season every furrow is used.

Still another practice is to seed crops directly in the furrow. This can be done with several row crops, such as beans and corn. A related practice involves leaving or placing crop residues in the furrow to slow the velocity of the water and to filter out the sediment.

Herbicide use reduces cultivation requirements which also reduces erosion and sediment losses on irrigated land.

Furrow erosion remains a serious problem on irrigated land, but much is being done to control it. Current technology provides several alternative control measures that farmers can apply according to conditions in their fields.

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